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**EFFECT OF A HIIT PROGRAM PERFORMED IN DIFFERENT
SIMULATED ALTITUDE CONDITIONS ON PHYSIOLOGICAL
VARIABLES RELATED WITH STRENGTH AND ENDURANCE.**

Trabajo de Fin de Grado en CC de la Actividad Física y el Deporte

Presentado por:

D. CARLOS LEÓN MUÑOZ

Tutorizado por:

D. FLORENTINO HUERTAS OLMEDO

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ABBREVIATION INDEX

1RM: One repetition maximum

2,3-DPG: 2,3-diphosphoglycerate

ADP: Adenosine diphosphate

AMP: Adenosine monophosphate

AMPK: AMP-activated protein kinase

ATP: Adenosine triphosphate

BP: Barometric pressure

CO₂: Carbon Dioxide

DBP: Diastolic blood pressure

EPO: Erythropoietin

FiO₂: Reduced inspired fraction of oxygen

Hb: Haemoglobin

HH: Hypoxia hypobaric

HIIT: High Intensity Interval Training

HR: Heart rate

HR max: Maximum heart rate

IHT: Intermittent hypoxic training

LASS: La steady state

LJMU REC: Liverpool John Moores University Research Ethics Committee

MAS/MAP: Speed or maximum aerobic power

mmHg: Millimetre of mercury

mmol/L: Millimoles per litre

NH: Normobaric Hypoxia

p38 MAPK P38: mitogen-activated protein kinases



pH: Power of hydrogen

PiO₂: Inspired partial pressure of oxygen

PO₂: Partial Pressure of Oxygen

PGC-1 α : Peroxisome proliferator activated receptor coactivator protein 1 α

RC: Respiratory coefficient

RPE: Rate of perceived exertion

SBP: Systolic blood pressure

SD: Standard deviation

VO₂: Volume oxygen

VO₂max: Maximum oxygen volume

VT1: First Ventilatory Threshold

VT2: Second Ventilatory Threshold

W: Watt





ABSTRACT



1 ABSTRACT

The objective of the study is to investigate the potential impact of cycling High Intensity Interval Training (HIIT) at sea level or simulated altitude has on Aerobic fitness level, blood lactate accumulation and strength, of the lower limbs of untrained individuals to improve performance and develop a method of training. The study was randomly divided into 2 groups (hypoxia/sea level) and for 4 weeks, training was performed twice a week for the duration of the sessions lasted no more than 30 minutes. The training itself consisted of cycling HIIT, working at 85-90% of maximum heart rate during 1-minute sprint intervals, followed by 1-minute rest periods. For the group that exercised at altitude the oxygen saturation was set at approximately 16%. During the first week there were four 1-minute sprints and after each first week the sprints will increase by two repetitions each week. Results show after training program significant increases in maximum oxygen volume (VO_{2max}) ($p < 0,001$), haemoglobin concentration ($p = 0,004$), resting heart rate ($p < 0,001$), lactate threshold in Watt (W) ($p < 0,001$), Systolic blood pressure (SBP) ($p = 0,007$), in the moment pre-post in favour post. There were no significant differences between the increases in any of the performance parameters mentioned between groups ($p > 0,05$). In addition, neither one repetition maximum (1RM) nor diastolic blood pressure (DBP) were significantly changed in the effect moment or group ($p > 0,05$). These data suggest the time expended under normobaric hypoxia conditions is insufficient to improve aerobic and anaerobic capacity at sea level in untrained subjects. Therefore, if there is any advantage in intermittent hypoxia training to improve performance at sea level, it would not appear with a short exposure protocol as in the present study.

Key words: Normobaric Hypoxia, Sea level, HIIT, aerobic, anaerobic.





JUSTIFICATION



2 JUSTIFICATION

The purpose of the study chosen for this TFG is due to personal reasons, related to my academic studies.

During the present course I have done the External Practices of the Degree at the John Moores University of Liverpool. From the area of physiology, a research project based on the application of HIIT in hypoxia has been undertaken to develop training programs, with the aim of improving (VO_2max), lactate threshold etc. It is for this reason that I decided to undertake the TFG related to a part of the study that has been carried out.

For years, researchers have focused on the study of VO_2max enhancement to improve physical performance. However, in the last three decades the use of high intensity interval training as a substitute for continuous training and possible ways to optimize this training by performing it at simulated altitude are being studied.

In order to undertake this project, it is important to know the previous work that has been done. In addition, it is fundamental to know the resulting adaptations to exposure to hypoxia and high intensity interval training, since the characteristics of these are those that justify this project.

In this way, we seek to analyse this methodology of use applied in our intervention, in order to conform a resource to be used by the professionals of Physical Activity and Sport for the improvement in sport performance.





THEORETICAL FRAMEWORK



3 THEORETICAL FRAMEWORK

In this theoretical contextualization, we try to explain in the first place, what the HIIT consists of, its components and its physiological responses, in this way we try to understand how this training method works, the different variables that have to be applied when programming a session and the responses that the organism will suffer, if it is done correctly.

Secondly, it is intended to define what hypoxia is, what physiological responses are produced by the exposure of a subject to it and finally to contextualize the simulated intermittent hypoxia that will be performed in the present study.

3.1 HIGH INTENSITY INTERVAL TRAINING

3.1.1 Definition High Intensity Interval Training

Globally, HIIT can be defined as physical exercise that combines short intermittent burst of vigorous activity with periods of light intensity or rest. Gibala et al. (2012) point out that, based on this idea, there can be many variations of HIIT, which will give rise to specific physiological adaptations (figure 1) depending on how different factors are considered (intensity, duration, number of intervals, duration, recovery periods, etc.) Also, HIIT can be understood as discontinuous efforts made at an intensity above the anaerobic threshold alternated with recovery phases (Buchheit & Laursen, 2013).

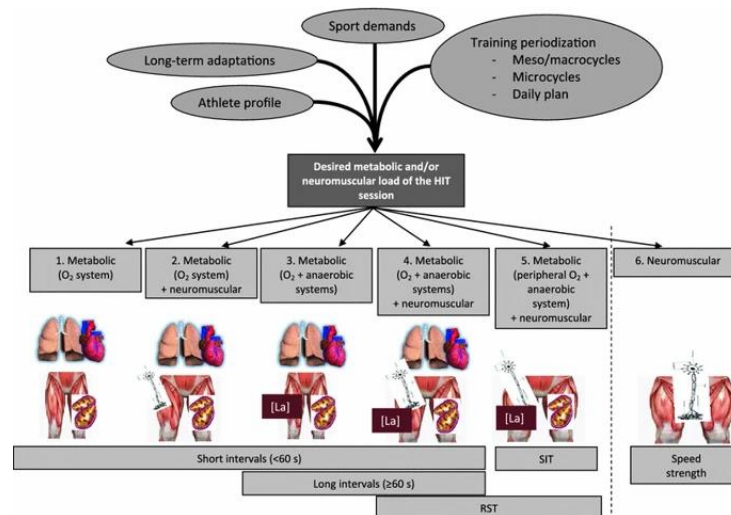


Figure 1. Based on the expected acute physiological response to HIIT (Buchheit & Laursen, 2013)

More specifically, different authors define the term HIIT based on different parameters. Firstly, Chicharro (2013) argues that HIIT training takes place at phase III or metabolic intensity (figure 2). This phase takes place when workloads approach the anaerobic threshold (80-85% of $\text{VO}_{2\text{max}}$). He then adds that for the training session to be adequate, the total time of all the intervals should exceed the total duration that the athlete could endure at the same intensity until exhaustion (Laursen, 2018). Batacan et al. (2017) defined HIIT as a type of training characterized by workloads with intensities (85% to 250% $\text{VO}_{2\text{max}}$ over a duration of 6 seconds to 4 minutes) interspersed with active recovery (20% to 40% $\text{VO}_{2\text{max}}$ over a duration of 10 seconds to 5 minutes). Finally, Robinson et al. (2014) exposed HIIT as the achievement of short to long duration intervals (figure 3) (45 seconds to 2-4 minutes) at intensities above the anaerobic threshold (greater than 80% of $\text{VO}_{2\text{max}}$), alternated with periods of duration (1-5 minutes) at low intensity or by taking breaks.

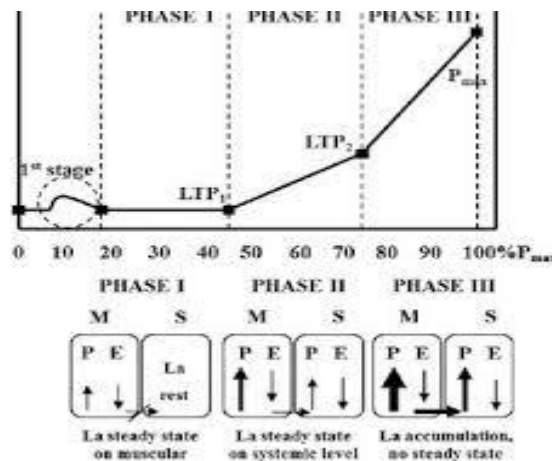


Figure 2. Three-phase model of lactate (Tschakert & Hofmann, 2013)

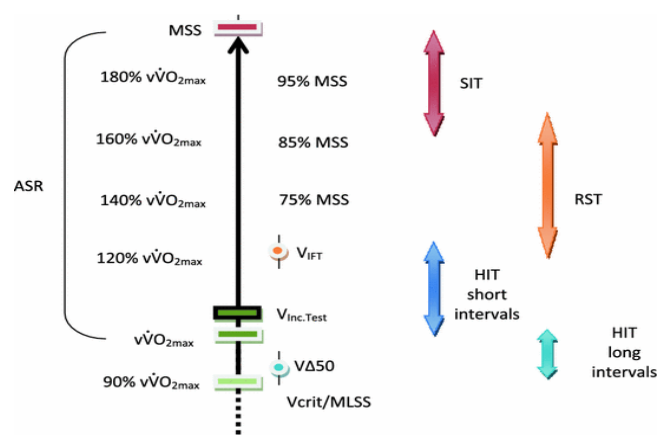


Figure 3. Intensity based in VO_{2max} performed for the different short-long HIIT interval (Buchheit & Laursen, 2013)

The purpose of HIIT would be to increase the use of the physiological systems used during specific resistance exercise, in greater proportion than that required during the activity (Laursen & Jenkins, 2002).

The main objective of this training methodology is to improve VO_{2max} , due to the intensity at which a HIIT session is performed. Therefore, the aim is to keep the athlete as long as possible at or near the VO_{2max} (Laursen, 2018).

At the metabolic level, it is characterized by a preponderance of the glycolytic system. Because the interval series consists of short to moderate durations, with intensities above the anaerobic threshold and recovery periods, improvements in oxidative and glycolytic energy

systems are achieved compared to constant speed training (Robinson et al., 2014). The cardiocirculatory system is progressively driven to peak performance (VO_2max) and the internal cellular environment is increasingly acidic (Chicharro, 2013).

An advantage of using HIIT is that similar or greater results are achieved, taking less time to perform, compared to training methods that use a lower training intensity (Bartlett et al., 2018).

In the health field, HIIT has also been considered the most efficient way to improve health at a cardiorespiratory level and reduce mortality in older people (Karlsen et al., 2017).

3.1.2 Main components of the HIIT

The main difference in planning an HIIT session versus a continuous training session resides in the number of variables that must be manipulated. While in continuous training only the duration and intensity need to be controlled, in HIIT nine components need to be controlled: the main ones will be the intensity, the duration of the intervals, the duration and the intensity of the recovery. But it is also relevant to optimise the number of intervals and sets, the time between sets and the warm-up and cool-down period (Chicharro, 2018). This is supported by Tschakert & Hofmann (2013) which stated that to design an interval training session, it is necessary to control nine variables, making the structure of the training program difficult.

The importance of properly controlling each variable will impact on the body's responses at the metabolic, cardiopulmonary and neuromuscular levels. This will lead to different adaptations. Planning a training session based on physiological processes that include periods of recovery shows a greater degree of difficulty and even more understanding of the relationship between response and adaptation (Laursen, 2018). Therefore, it is necessary to develop each of these variables in the next sections.

3.1.2.1 Intensity of intervals

The intensity of the intervals is described as the main component in planning an HIIT session. Several physiological variables can be used to control intensity (Billat, 2001).

First, the use of heart rate (HR) as a means of controlling intensity could be a good alternative due to its low cost and high correlation between % HR reserve and $\text{VO}_{2\text{max}}$. To do this, the intensity should be adjusted to 90-95% of the HR reserve, which would place the athlete in an optimal situation of HIIT intensity. The problem that appears when using the heart rate is that the HR cannot give information once the speed or power associated to the $\text{VO}_{2\text{max}}$ is exceeded when it reaches a stable level. In addition, at the beginning of the exercise the response of the $\text{VO}_{2\text{max}}$ is slower than that of the HR, this can overestimate the intensity produced (Billat, 2001).

Another option to manipulate the intensity in the HIIT intervals is the rate of perceived exertion (RPE). To place the athlete between 18-19 in the Borg scale (6-20), would be the optimal intensity to perform a HIIT session. But, to be able to adjust this intensity will depend on the experience of the athlete, that is to say if the athlete does not have much experience, this variable, will not have great reliability (Dishman et al., 1987).

A third option, the use of maximum aerobic speed or power (MAS/MAP) is probably the best option to program a HIIT session (Billat, 2001). The MAS/ MAP, constitutes the lowest power or speed at which the $\text{VO}_{2\text{max}}$ is reached. It is therefore necessary to perform a maximum intensity stress test with analysis of breathing phases where it is established at which values the stable plateau of the VO_2 is reached. The MAS/MAP constitutes the union of the energy cost and the $\text{VO}_{2\text{max}}$ in a single factor. To use this variable in a HIIT session, the intensity must be 100% of the MAS/MAP (Billat & Koralsztein, 1996).

3.1.2.2 Length of intervals

The next point to be discussed would be how long each interval should last. It is necessary to know how long it takes to reach the VO_{2max} by developing an intensity corresponding to the MAS/MAP, in order to adjust the optimal time of the interval in a session. It will depend to a great extent, the training status of the athlete and the exercise performed, to reach a 100% intensity of the MAS/MAP the VO_{2max} (Guiraud et al., 2012).

More practically, Wen et al. (2019) proposed that the duration of an interval should be equal to or longer than the time needed to reach the VO_{2max} at a defined intensity. They proposed adjusting the duration of the intervals by 3 minutes as a practical and direct option, due to the fact that the various investigations maintain that between 2 and 4 minutes the subjects could maintain values close to the VO_{2max} .

3.1.2.3 Intensity and duration of recovery

The recovery time between intervals has to be sufficient to allow the athlete to reach the target time in the next interval at or near the VO_{2max} before exhaustion, but trying to be as short and intense as possible (Wiewelhove et al., 2018).

Considering the recovery time should be based on the duration of the interval, a HIIT session could be planned in a general and initial way, with a 1:1 ratio (Chicharro, 2018). Another possibility to estimate the recovery time in a more optimal way would be to use a 30% and 60% of the duration until exhaustion in MAS/MAP (Nédélec et al., 2013).

The intensity of recovery between intervals can be planned passively, with the aim of maximizing working capacity in subsequent intervals (Wahl et al., 2013) or it can be planned actively with the aim of maintaining a minimum level of VO_2 , decreasing the time needed to reach the VO_{2max} in subsequent intervals (Wiewelhove et al., 2018).

3.1.2.4 Number of interval and series

The goal of the HIIT is to accumulate in the total of all intervals about 10 minutes at 95% of the VO_{2max} . This idea should be taken into consideration as a starting point for planning the HIIT session. Not all of the time spent performing the exercise will be at 90-95% of the VO_{2max} ; this time is approximately 44% of the total exercise duration (Millet et al., 2003).

Chicharro (2018) argues that "if 3-minute intervals are applied, the number of repetitions should be between 6 (total time: 18 min, time at VO_{2max} = 8 min (18×0.44)) and 8 (total time: 24 min, time at VO_{2max} = 10.5 min (24×0.44))" (p63). In consideration of this minimum time needed, proposes 7 as the number of optimal intervals in a HIIT session. The use of series in a protocol of 7 intervals, with a duration of 3-4 min, could be structured in a single series, it would not be necessary to divide it into series. If protocols are used in which the intervals are shorter, then it would be necessary to divide it into series (Chicharro, 2018).

3.1.2.5 Warm-up and cool down

The importance of the warm-up is based on the idea of optimizing the training to be performed. Chicharro (2018) proposes the following warm-up model: 10 minutes of exercise at the lactic threshold/ First Ventilatory Threshold (VT1), then two 1-minute intervals at the intensity of Second Ventilatory Threshold (VT2), alternating with 30 seconds of active recovery at the intensity of the lactate threshold. The return to calm should be performed of 15 minutes of continuous exercise at low intensity (70-80% of lactate threshold/VT1).

3.1.3 Physiological adaptations

Understanding what HIIT is and how to develop a training session is fundamental to achieve the physiological adaptations that are aimed in each sport modality and therefore its repercussion on performance.

The main adaptation targeted by HIIT training is VO_{2max} improvement. VO_{2max} improvement is related to a set of adaptations at a central level, related to cardiopulmonary capacity and oxygen utilization (MacInnis & Gibala, 2017). In addition, authors such as Tschakert & Hofmann (2013) defend the existence of adaptations at the peripheral level, associated with the quality and quantity of muscle enzymes or the accumulation of lactate.

3.1.3.1 Central adaptations

With regard to the cardiovascular level, Laursen & Jenkins (2002) argued that due to the stability with no variation of the maximum heart rate (HR max) through HIIT training, the improvements in the distribution of oxygen to the muscles may be due to the increase in the systolic volume. This increase may occur due to an increase in cardiac filling pressure and through increased contractile force of the ventricle.

According to Tschakert & Hofmann (2013), improvements in heart function due to HIIT are due to an increase in volume in the left ventricle, resulting in a reduction in peripheral resistance. Also, it produces a higher final systolic and diastolic volume.

At thermoregulation level, when the athlete is exposed to high intensity exercise, the central temperature rises (around 40°C) increasing the plasma volume, thus adapting to the heat. A greater tolerance to heat can be appreciated by physically active subjects. This adaptation is produced due to an increase in the sweating rate. Thus, heat tolerance can be attributed to a possible response to HIIT, due to the fact that trained athletes have an improved

capacity to sweat, in addition to better blood supply (Laursen & Jenkins, 2002).

3.1.3.2 Peripheral adaptations

Among this type of adaptation, the capacity of the muscle to produce and use Adenosine triphosphate (ATP) will be highlighted. Improvements in VO_2max are mainly produced by adaptations of the muscle oxidative potential and increased mitochondrial and mitochondrial enzyme activity. Increases in oxidative and glycolytic enzyme activity have been demonstrated through the application of HIIT (Tschakert & Hofmann, 2013).

At the molecular level, due to the high intensity that develops during HIIT, there is a high activation of AMP-activated protein kinase (AMPK) and P38 mitogen-activated protein kinases (p38 MAPK) (Gibala et al., 2009).

Phosphorylation and activation of peroxisome proliferator activated receptor coactivator protein 1 α (PGC-1 α) is directly implicated by both AMPK and MAPK signalling pathways. PGC-1 α has been considered the key to mitochondrial biogenesis (Wu et al., 1999).

In this way, the increase of PGC-1 α is hypothesized as a major transcription factor to increase mitochondrial protein storage and therefore mitochondrial biogenesis. The activation of PGC-1 α may possibly be related to changes in the intramuscular ATP-ADP(adenosine diphosphate)-AMP(adenosine monophosphate) ratio and the concurrent activation of HIIT-associated AMPKA (Chen et al., 2000).

Regarding the accumulation of lactate in the blood it is explained two different responses depending on the duration of the intervals. First, long intervals of 2-3 minutes at intensities close to the VO_2max potency produce high blood lactate concentrations (about 16.6 millimoles per litre (mmol/L)) (Rønnestad et al., 2014). Secondly, short intervals of 30 seconds or 1 minute at peak power produce a lower lactate concentration (2 mmol/L) and are well

tolerated for 1 hour. They conclude that the higher the peak power produced in the intervals, the duration of the intervals should be shorter, maintaining Lactate steady state (LASS). An advantage of training in LASS would be to plan training with more volume, which means more time can be spent (Chicharro, 2018).

In terms of the intensity of recovery, Billat et al. (2001) argues, that training with high levels of lactate can facilitate the elimination of lactate in subsequent sessions. Using a 15-second -15-second protocol, with higher recovery intensities, improvements in lactate concentration levels are obtained in future sessions at the same intensity, compared to lower recovery intensities.

Other adaptations produced by low-volume HIIT after several weeks include the inclusion of higher resting glycogen content and reduced glycogen utilization associated with an increased capacity for lipid oxidation in skeletal muscle (Gibala et al., 2006).

One adaptation caused in healthy, young women and men is increased compliance in peripheral, but not central, arteries to low-volume HIIT exposure (Rakobowchuk et al., 2008). In their protocol, they also observed increased endothelial function in trained legs when compared to a higher volume of continuous training of moderate intensity.

Sometimes training is performed at altitude to optimize training. In this study, exposure to hypoxia was combined with the use of HIIT to enhance a sea level HIIT application. Therefore, it is necessary to understand what hypoxia exposure is and which adaptations it causes for the organism.

3.2 HYPOXIA

3.2.1 Definition

Briefly, hypoxia can be understood as a reduction in the level of oxygenation in tissues

(Sarkar et al., 2017).

It is necessary to understand that above sea level the barometric pressure is close to 760 millimetre of mercury (mmHg). Therefore, considering that oxygen molecules make up 20.93% of the air and that the partial pressure of oxygen is the part of the barometric pressure that oxygen molecules exert in the air, at sea level it is 0.2093 times 760mmHg = 159mmHg (Kenney et al., 2014).

The concept of hypoxia is generally understood as the reduction of oxygen availability. Thus, hypoxia is caused by a reduction in total air. When the altitude is increased, the total air pressure is reduced, so while the proportion of oxygen remains stable at 21%, the partial pressure of oxygen is similarly reduced (Nikinmaa, 2013).

More specifically, hypoxia can be understood according to (Millet et al., 2012), as combinations of reduced barometric pressure (PB) or a reduced inspired fraction of oxygen (FiO_2), which later ends up in the inspired partial pressure of oxygen (PiO_2) less than 150 mmHg (figure 4).

When humans ascend to high altitudes the PO_2 (Partial Pressure of Oxygen) is reduced, this significantly affects physical performance. The decrease in air pressure causes a decreased PO_2 in the inspired air, reducing pulmonary oxygen diffusion from the lungs and oxygen transport to the tissues. A small PO_2 is known as hypoxia (Kenney et al., 2014).

Two forms of hypoxia conditions can be artificially generated: Firstly, through hypoxia hypobaric (HH; $FiO_2 = 20.9\%$; $PB < 760$ mmHg) is based on the decrease of the environmental barometric pressure simulating the alveolar pressure conditions of all gases at altitude (Álvarez, 2014). Secondly, normobaric hypoxia (NH; $FiO_2 < 20\%$; $PB \approx 760$ mmHg) consists of the reduction of ambient oxygen concentration by simulating partial pressure of oxygen at altitude (Degache et al., 2012).

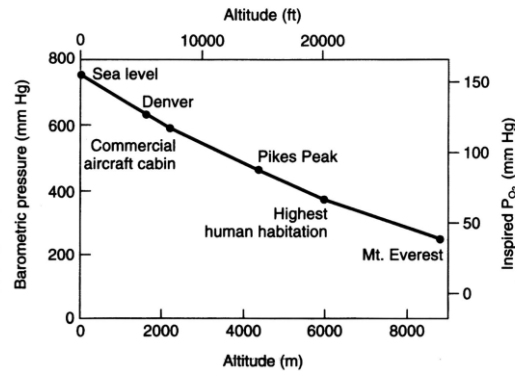


Figure 4. *O₂ pressure adaptation at altitude (Kenney et al., 2014)*

3.2.2 Physiological responses to hypoxia

3.2.2.1 Cardiorespiratory responses.

The cardiorespiratory system in response to exercise under hypoxic conditions responds by reducing aerobic performance. Acute responses and long-term responses are produced (Imray et al., 2011) (figure 5).

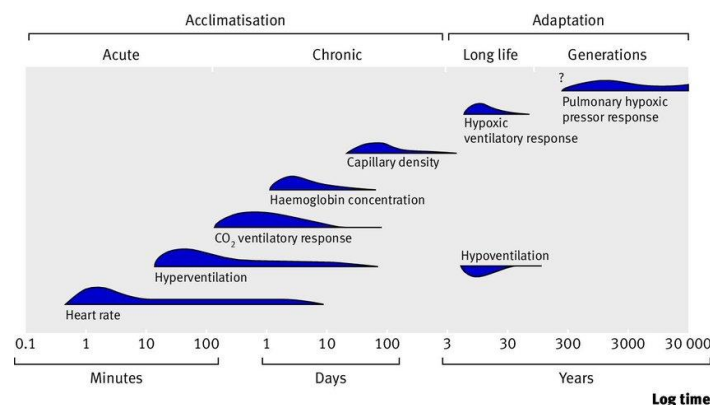


Figure 5. *Acute responses and long-term responses to hypoxia (Imray et al., 2011)*

The organism when exposed to a condition of hypoxia initially produces a hyperventilation, by reducing the partial arterial pressure of carbon dioxide (CO₂), thus increasing that of O₂. This response is difficult to maintain over time, due to the increased affinity of haemoglobin for O₂, and as a result, it makes it difficult to release it into the tissues

(Cerretelli & Samaja, 2003). Associated with this response is increased heart rate. Bernardi et al. (2001) associates increased heart rate with decreased vagal tone.

In the long term there is an increase in the number of mitochondria to improve tissue oxidation. Also, in the cell membrane the active transporters of O₂ are activated producing variations in the permeability of this gas (Tafalla, 2007).

Another response is the stimulation of the sympathetic system that produces an increase in heart rate (Peacock, 1998).

During aerobic exercise the efficiency of the cardiorespiratory system decreases. Among the mechanisms that produce this decrease in aerobic capacity are hypoventilation, inadequate ventilation-perfusion and limited alveolar-capillary diffusion (Bailey & Davies, 1997).

One of the most targeted responses in altitude training is an increase in erythropoietin (EPO). There is a direct correlation between the creation of EPO and the supply of oxygen to the body. It is therefore understood that as long as the supply of oxygen is sufficient the creation of EPO is maintained, but when the supply of oxygen is reduced, a large increase occurs due to the existence of an alarm signal to the detriment of the body's vital functions (Eckardt et al., 1990).

A greater effort when exercising in hypoxia causes adaptive responses at the heart level, a greater cardiac ejection capacity clarifies the improvement in oxygen consumption. Svedenhag et al. (1997) observed an increase in the mass of the left ventricle (9-10%) after a training program at 1900m.

In the long term an increase in the number and openings of blood capillaries is created, decreasing peripheral muscular vascular resistances and reducing the distance of diffusion of O₂ in the fibres (Velarde et al., 1993).

Also, a peripheral vasodilation is produced to increase the blood volume that reaches

the tissues, an alveolar vasoconstriction, to increase the time that the blood oxygenates the lungs. (Tafalla, 2007).

3.2.2.2 Blood/haematological responses

The increase in EPO formation is a much-desired response in some sports, such as cycling. It is well known, that when human beings are exposed to hypoxic conditions there is an increase in EPO production. Berglund (1992) observed an increase of 1% per week with stays between 1829 and 3048m.

This hematopoietic response is immediate when the athlete is exposed to hypoxic conditions (first 24 hours) (Levine & Gundersen, 1997). However, a duration of exposure between 14 and 21 days is considered ideal for sports performance (Chapman et al., 2013; Schuler et al., 2007).

Increased secretion of erythropoietin and haemoglobin favours increased availability of red blood cells, resulting in increased O₂ (Eckardt & Bauer, 1989). In a study performed by Rodríguez et al. (1999) no increase in blood cells was observed and no increase in blood viscosity was produced.

Another adaptation is observed in the affinity of Hb (haemoglobin)-O₂, due to the increase of 2,3-diphosphoglycerate (2,3-DPG), is a powerful allosteric effect of the binding properties of O₂ with haemoglobin). This causes an increase in P50 (50% saturation pressure) producing a reduction in the affinity of haemoglobin with O₂ and facilitating its release into tissues (Tafalla, 2007).

Also, a transport of O₂ is favoured due to a greater difference in power of hydrogen (pH) between venous and arterial blood (Cerretelli & Samaja, 2003).

3.2.2.3 Metabolic responses

Regarding to the metabolic level, as a result of exposure to hypoxia, the processes of glucose oxidation and metabolism are improved, increasing the absorption of glycogen by muscle cells and improving aerobic performance (Katayama et al., 2010).

This change in energy metabolism is explained by the fact that the respiratory coefficient (RC) is close to 1 (in the respiratory coefficient values close to 1 imply the metabolization of carbohydrates, values of 0.7 imply the metabolization of lipids). In response to this change, oxygen uptake at the respiratory surface and O₂ diffusion into the blood are increased (Wenger, 2000).

The increase in muscle glycogen during hypoxic conditions and training produces a higher level of energy imbalance at the muscle level, associated with higher levels of plasma and muscle lactate. This induces a situation of physiological incapacity to clear muscle lactate and to regulate the intrafibrillary pH, which can lead to a limitation of contraction and a decrease in exercise intensity (Brooks et al., 1992; Kjaer et al., 1988; Lundby & Van Hall, 2002).

3.2.3 Intermittent Hypoxia

Intermittent hypoxia was developed as an alternative option to the hypoxia that humans are exposed to when they climb to high altitudes.

The use of intermittent exposure allows us to avoid the disadvantages of prolonged exposure: muscular atrophy, loss of hunger and weight, fatigue, sleep disturbance, hypertension, neural and vascular problems, cognitive deficiencies, mitochondrial oxidative stress, etc. In turn, it can generate adaptations typical of chronic exposure: cardiovascular, respiratory, metabolic, etc. (Banchero et al., 1987; Neubauer, 2001; Zhuang & Zhou, 1999).

Rodríguez et al. (1999) also argue in favour of intermittent hypoxia, because it makes it possible to acclimatise to high altitudes without the inconvenience of having to go to the mountains, and the cumulative effect begins from the first session. The fact that it is intermittent and not continuous allows us to save the time invested in acclimatization and allows us to maintain our pace of life.

Recently attention has been given to a form of training, intermittent hypoxic training (IHT), which allows the athlete to "train high and live low", where intermittent periods of hypoxia dedicated to training alternate with prolonged stays at sea level. In this way we try to improve the adaptations that would be achieved by performing a training program at sea level (Levine, 2002).

3.3 HIGH INTENSITY INTERVAL TRAINING IN HYPOXIA

High intensity exercise combined with exposure to hypoxia is an enough stimulus to improve performance compared to training at sea level. This may be helpful for athletes who participate in group sports, where play is intermittent. These sports are characterized by efforts that place the athlete above the anaerobic threshold, but during the course of an aerobic test (Morton & Cable, 2005).

Altitude training to improve performance at sea level is a highly researched area, but despite this there is no conclusive evidence of the best intervention program to optimize the athlete's performance. Thus, the objective of the present study is to test the efficiency of high intensity interval training in simulated hypoxic conditions, in a short period (4 weeks) in aerobic and anaerobic performance at sea level.

The present study tries to provide new evidence to know the effect of simulated altitude on physiological responses resulting from HIIT.



OBJECTIVES



4 OBJECTIVES

4.1 GENERAL OBJECTIVE

1. Evaluate the effect of a 4 weeks training program based on HIIT under different conditions of simulated altitude on physiological variables related with strength and endurance performance.

4.2 SPECIFIC OBJECTIVES

1. To explore the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on VO_2max .

2. To analyse the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on lactate threshold.

3. To study the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on 1RM.

4. To investigate the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on heart rate

5. To explore the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on RPE.

6. To study the effect of simulated altitude on the adaptations induced by a 4 weeks HIIT program on blood pressure.





COMPETENCES



COMPETENCES

5.1 GENERAL COMPETENCES

GC1. Understand scientific literature in English and other languages of significant presence in the scientific field through proper information management.

GC2. To know how to apply information and communication technologies (TIC) to the field of Physical Activity and Sport.

GC3. Transmit any related information appropriately both in writing and orally.

GC4. Use the Internet properly as a means of communication and as a source of information.

GC5. To develop habits of excellence and quality in professional practice.

GC6. To be able to make critical reasoning using the knowledge acquired.

GC7. Transmit the knowledge acquired to both specialists and non-specialists in the subject in question.

GC8. Develop skills for creativity, initiative and entrepreneurship.

GC9. To know and understand the object of study of the CC of Physical Activity and Sport.

5.2 SPECIFIC COMPETENCES

SC1. To know and understand the effects of a HIIT training program in Hypoxia.

SC2. To know and understand the physiological and biomechanical effects that condition the practice of an HIIT training program in Hypoxia.

SC3. To know and apply the physiological, biomechanical, coordination and cognitive



principles of sports training.

SC4. To know and understand the structure and function of the different physiological systems.

SC5. To evaluate the performance of a HIIT training program in Hypoxia.

SC6. To evaluate the physical condition through VO₂Max test and lactate threshold test.

SC7. To plan, develop and control the training process in its different levels.

SC8. To plan, develop and evaluate the performance of physical-sports activities programs.



METHOD



6 METHOD

6.1 PARTICIPANTS

Fifteen healthy, untrained male and female (N=8 and N=7 respectively) Liverpool John Moores students volunteered to take part in the intervention. Fourteen participants (7 male and 7 females) successfully completed the intervention (see Table 1 for participant characteristics), the participant who did not finish was for personal reasons. These participants all met the inclusion criteria of 18-30 years of age; Body mass index (BMI) >18 but <30; participate in <4 hours per week of moderate/high intensity exercise or lower limb resistance training; being free from any recent musculoskeletal or cardiovascular problems and have a VO_2max <60ml.kg⁻¹.min⁻¹.

Table 1.

Descriptive statistics (Mean \pm SD) of Pre-training characteristics of the sea level and hypoxic training groups.

	Hypoxic	Sea level
Age (years)	20 \pm 1	19 \pm 1
Height (cm)	176.7 \pm 11.5	173.2 \pm 7.4
Weight (kg)	72.0 \pm 11.2	71.7 \pm 16.1
BMI	23.0 \pm 1.9	23.7 \pm 4.0
Fat%	21.1 \pm 5.9	24.2 \pm 11.9
Muscle%	38.1 \pm 3.6	35.8 \pm 6.1
Haemoglobin (g/L)	149 \pm 21	136 \pm 5
VO_2max (ml/kg/min)	41 \pm 7	35 \pm 10
1RM avg (kg)	179 \pm 48	138 \pm 32
Lactate threshold (W)	145 \pm 30	87 \pm 30
Resting heart rate (bpm)	79 \pm 9	87 \pm 10
Resting SBP avg (mmHg)	122 \pm 11	125 \pm 11
Resting DBP avg (mmHg)	68 \pm 5	73 \pm 6

6.2 PROCEDURE

6.2.1 Sample recruitment

Participants were recruited predominantly via a recruitment email sent out to the School of Sport and Exercise Science. Other methods were via “word of mouth” and recruitment posters put up at various locations around the university campus.

Participants were informed about the nature and risk of the intervention and written informed consent was given by the participants. The study received ethical approval from Liverpool John Moores University Research Ethics Committee (LJMU REC) (ethical approval number U19_SPS_220).

6.2.2 Test Protocol

Participants were fitted with a heart rate monitor upon arriving to the lab and were asked to rest for 5 minutes before any measurements were taken. Resting haemoglobin and lactate concentrations, heart rate and blood pressure were also obtained using a Hemocue (Hemocue AB, Ängelholm, Sweden), Biosen C-Line analyser (EFK Diagnostics, Cardiff, United Kingdom), Polar Electro, Kempele, Finland) and electronic sphygmomanometer (Dinamap, GE Healthcare, Chicago, United States) respectively. Bio-impedance measurements (SECA, Hamburg, Germany) were taken to determine BMI (determined via bio-impedance scales) and muscle/fat mass in the Tom Reilly Building. Height and weight were determined prior to this measurement using a stadiometer and electric scale respectively (SECA, Hamburg, Germany). A maximum incremental cycling test, to exhaustion, in normoxic conditions was then performed using a cycle ergometer (Lode BV, Groningen, The Netherlands), in order to determine lactate threshold and VO_2max simultaneously. Participants then performed a 1

repetition maximum (1RM) test on a separate day using a leg press dynamometer (Concept2 DYNO, Vermont, United States) in the CETL gym at Primrose Hill. This was to determine leg strength and was chosen over back squat 1RM due to safety reason and possible limited participant experience of performing a traditional back squat 1RM.

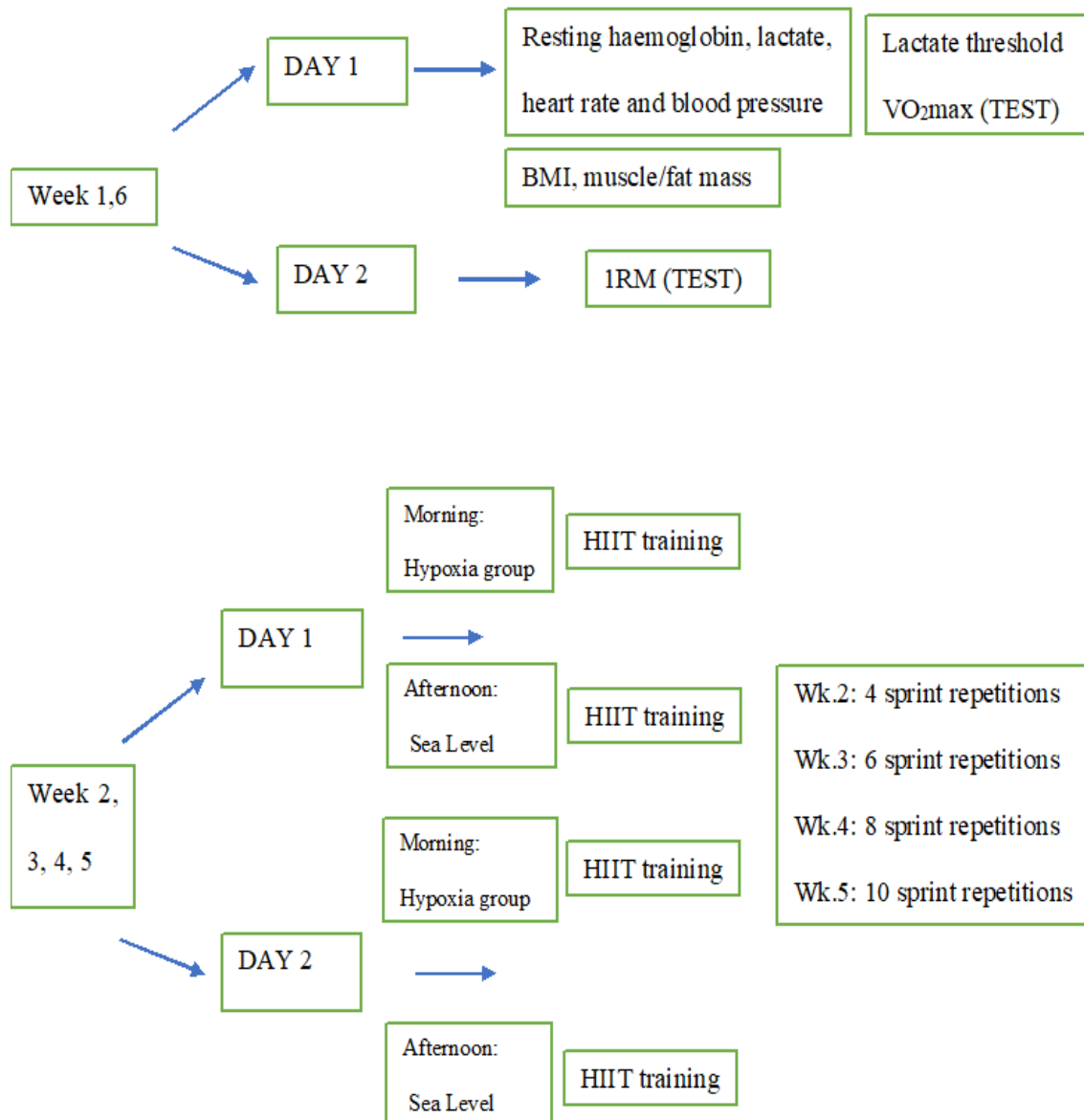


Figure 6. Schematic representation of the experimental test and protocol timing.

6.3 TRAINING PROGRAMME AND PROTOCOL

The intervention took place over 6 weeks in total, 4 of which were the HIIT training, the other two weeks were used for the initial and final tests. Each part of the intervention followed a randomised, controlled single-blind design consisting of two experimental training sessions per week under either a normoxic (N=7, 4 males and 3 females) or hypoxic (N=7, 3 males and 4 females) condition. Participants were conducted in the environment chambers (T.I.S.S, Hampshire, England) at John Moores University. Average and maximum heart rate and power output were obtained from each participant during the sessions using the Wattbike app, along with RPE and SpO₂ levels at the end of each sprint. All exercise sessions were performed on Watt Bikes (WattBikes Ltd, Nottingham, England) and participants undergoing hypoxic training were allowed to acclimatise for 5 minutes prior to a 5-minutes warm up at a self-selected intensity. The first week of training consisted of 4 repetitions of 1-minute sprint intervals at $\geq 85\text{-}90\%$ maximum heart rate in accordance with recommended exercise guidelines (ACSM, 1998), followed by 1-minute active recovery at $\geq 60\%$ maximum heart rate. This continued in the same manner, however, the number of the sprints repetitions increased by two each week (i.e. 4, 6, 8, 10 in weeks 1-4 respectively) and the longest sessions lasted approximately 30 minutes including the 5-minutes warm up and cool down. The load of the WattBike was self-adjusted in order to allow the participants to reach the calculated individual target heart rates, as stated above, within the minute sprint. Simulated altitude in the hypoxia group was set 2000m with FiO₂ set to 16.7%. The hypoxia stimulus was obtained by having participants breathe a nitrogen-rich gas composition when inside the chamber.

6.4 VARIABLES

6.4.1 Dependent variables

Group: the sample was divided into two groups at random.

- Control Group
- Experimental group

Moment:

- Pre: before training
- Post: after training

6.4.2 Independent variables

- VO₂max
- Lactate threshold (W)
- Haemoglobin concentration
- 1RM
- Blood pressure
- Heart rate

6.5 STATISTICAL ANALYSIS

To perform the statistical analysis, the JASP statistical software was used, performing an analysis of simple variance (ANOVA) and a repeated measures ANOVA to see the interaction between different variables (experimental group vs. control group) at two different times (pre and post). Partial Eta Square were used to investigate differences between the mean of pre-post test. Post hoc analyses (paired t-tests) were conducted to further explore significant

interactions.

6.6 WORK PLAN

The following table shows the development of this final year's project in a schematic view, with the corresponding timing of each event related to the different parts of the project.

Table 2.

work plan schedule

PHASES	TEMPORIZATION	INFORMATIONN
Origins of the topic	14/02/2020 – 30/02/2020	Data bases
<p>The first idea was to perform an investigation on how the ingestion of ice can benefit the improvement of the body temperature in Heat conditions, in football players. But a project came up, about HIIT training in Hypoxia conditions, and due to a high interest in investigating the effects that hypoxia can cause, to learn how to perform VO₂max tests, lactate threshold, etc. I decided to change my project, as I was very interested</p>		
Firsts steps	02/03/2020	Data bases and books
<p>Once I had a clearer idea of TFG, I presented my idea of the project to the tutor for approval. Later I followed the steps that he sent me in the sessions, and I wrote the abstract of the project, then I wrote the index and objectives of what would be the project for the tutor to review it.</p>		
Phase 1: Modification of the working guidelines	06/03/2020	Data bases
<p>After presenting a first draft of my objective, table of contents and summary of the TFG my tutor advised me to make several modifications so that it would be coherent, and I would not have any problem in performing and explaining my project in the theoretical framework.</p>		
Phase 2: Search	08/03/2020	Data bases and books
<p>During this phase I looked for all kinds of information on HIIT and Hypoxia separately. And I looked for articles that had conducted similar intervention protocols, implying that they studied the application of HIIT under hypoxic conditions. This search was undertaken in databases and books.</p>		
Phase 2: bibliographic review	16/03/2020	Data bases and books

The explanation, physiological adaptations of exposure to hypoxia on the one hand, and the explanation, components and physiological adaptations of the application of an HIIT on the other hand were written separately through a bibliographic review.

Phase 4: justification
30/03/2020
Data bases

When I had completed the theoretical framework, I focused on finishing all the parts of the work that I had left unfinished, such as the justification of the work, the competencies, etc. Before starting with the results and discussion of the study.

Phase 5: Correction of the work
15/04/2020

A short break was taken to review all the information that had been drafted and to make any necessary corrections in terms of both content and format. I also began to develop the graphics that were later included in the results

Phase 6: results
20/04/2020
JASP

This phase was the most complicated of the project, as I had never faced a task like this before. It consisted of analysing the data obtained in the study using JASP a computer program. And then to write it properly.

**Phase 7: discussion and
conclusion**
01/05/2020-
Data bases

Finally, the results obtained were discussed and compared with similar studies. And the conclusions of the work were written.

Phase 8: Bibliography
15/05/2020

Once the study has been completed, all the bibliography is properly placed, and the project is structured in accordance with the regulations in use.

Schedule																
Activities	February				March				April				May			
	Week1	Week2	Week3	Week4	Week1	Week2	Week3	Week4	Week1	Week2	Week3	Week4	Week1	Week2	Week3	Week4
1 Information on the different kinds of TFG																
2 Deciding on the TFG topic																
3 TFG sessions																
4 Meetings with the TFG tutor																
5 TFG Bibliographic Search																
6 Development of the TFG																

Figure 7. Schedule of the final project





RESULTS



7 RESULTS

7.1 PRELIMINARY ANALYSIS

By using the statistical treatment ANOVA (analysis of simple variance) it has been verified that there were no initial differences (prior to the beginning of the intervention program) between the two groups created (hypoxia group vs. normoxia group) in the different variables that could affect the results of the program. No statistically significant between group differences in height ($p = 0,513$), weight ($p = 0,988$), initial 1RM ($p = 0,086$), VO_{2max} ($p=0,211$), or haemoglobin concentration ($p=0,141$), neither in the resting heart rate ($p=0,138$), nor in the SBP ($p=0,621$), nor in the DBP ($p=0,113$). Only lactate threshold in (W) was different between groups at the initial level showing lactate threshold in (W) in the hypoxia group compared to the sea group ($F(1,12) = 9.591, p = 0,009, \eta_p^2 = 0,444$)

7.2 DESCRIPTIVE STATISTICS

Descriptive statistics of anthropometric and physiological characteristics of the whole sample and separately for Hypoxic and Sea subgroups are displayed in Table 3.

Tabla 3.*Descriptive statistics*

Variables	Mean \pm SD			
	Hypoxia Group		Sea level Group	
	PRE	POST	PRE	POST
Age (years)	20 \pm 1		19 \pm 1	
Height (cm)	176.7 \pm 11.5		173.2 \pm 7.4	
Weight (kg)	72.0 \pm 11.2	71.6 \pm 9.0	71.7 \pm 16.1	71.5 \pm 14.0
BMI	23.0 \pm 1.9	23 \pm 1.3	23.7 \pm 4.0	23.6 \pm 3.2
Fat (%)	21.1 \pm 5.9	21.4 \pm 5.3	24.2 \pm 11.9	24.7 \pm 10.7
Muscle Mass (%)	38.1 \pm 3.6	38.1 \pm 3.3	35.8 \pm 6.1	35.9 \pm 5.3
Haemoglobin (g/l)	149 \pm 21	156 \pm 20	136 \pm 5	148 \pm 13
VO ₂ max (ml/kg/min)	41 \pm 7	46 \pm 7	35 \pm 10	38 \pm 9
1RM avg (kg)	179 \pm 48	175 \pm 27	138 \pm 32	148 \pm 34
Lactate threshold (W)	145 \pm 30	175 \pm 44	87 \pm 30	130 \pm 26
Resting heart rate (bpm)	79 \pm 9	69 \pm 8	87 \pm 10	74 \pm 7
Resting SBP avg (mmHg)	122 \pm 11	116 \pm 12	125 \pm 11	116 \pm 8
Resting DBP avg (mmHg)	68 \pm 5	69 \pm 6	73 \pm 6	66 \pm 3

7.3 INFERENCE STATISTICS**7.3.1 Maximum oxygen volume**

Figure 3 shows the mean values obtained by both groups for maximum oxygen volume before and after the training program. Repeated measures ANOVA was performed on Mean VO₂max showing no significant difference in the improvement in VO₂max between the two

groups ($p=0,154$). A main effect of Moment ($F(1,12) = 78,757$, $p < 0,001$, $\eta_p^2 = 0,868$) in favour of the moment post in both groups were found. The intervention has had the same effect on both groups, since no significant differences in the interaction between the moment and the group are observed ($p=0,158$).

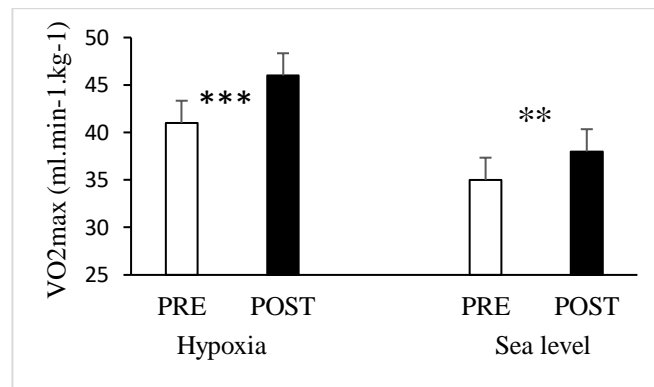


Figure 8. Mean VO₂max of the hypoxic and sea level training groups before and after training. Note: *** $p < 0,001$. ** $p < 0,01$

7.3.2 One repetition maximum

Repeated measures ANOVA were developed with mean of 1RM. No statistically significant differences were observed between the two groups ($p=0,091$). There are also no significant differences in the Moment pre-post ($p=0,614$), but the descriptive shows that there was only one trend to improve the RM in the sea level group. The intervention has had the same effect on both groups, since no significant differences in the interaction between the moment and the group are observed ($p=0,292$) (figure 4).

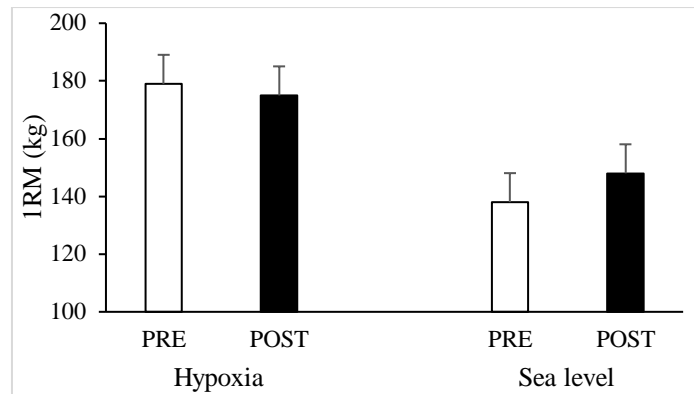


Figure 9. Mean 1RM of the hypoxic and sea level training groups before and after training

7.3.3 Haemoglobin concentration

Figure 5 shows the mean values obtained by both groups for haemoglobin concentration before and after the training programme. Repeated measures ANOVA results showed no significant difference in the improvement in haemoglobin concentration between the two groups ($p=0,221$). There was a significant main effect of moment ($F(1,12) = 12,330$, $p = 0,004$, $\eta_p^2 = 0,507$) in favour of the moment post but only in the group Sea level is statistical significant. The intervention has produced the same effect in both groups, because no significant differences are observed in the interaction between the moment and the group ($p=0,360$).

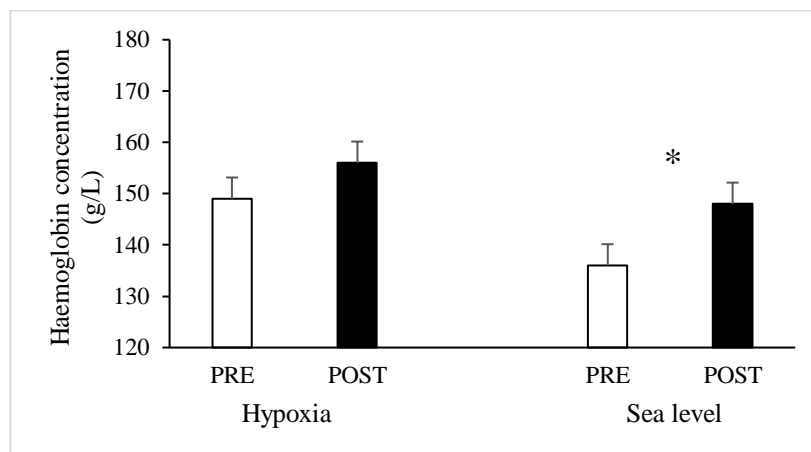


Figure 10. Mean haemoglobin concentration of the hypoxic and sea level training groups before and after training. Note: * $p < 0,05$.

7.3.4 Heart rate

Repeated measures ANOVA were developed with mean of heart rate. The improvement in heart rate did not differ between groups ($p=0,138$). Significant decrease in heart rate was observed ($F(1,12) = 26,153$, $p < 0,001$, $\eta_p^2 = 0,685$) in favour of the moment post. No differences have been shown in the interaction between groups and the pre-post effect ($p=0,437$) (figure 6).

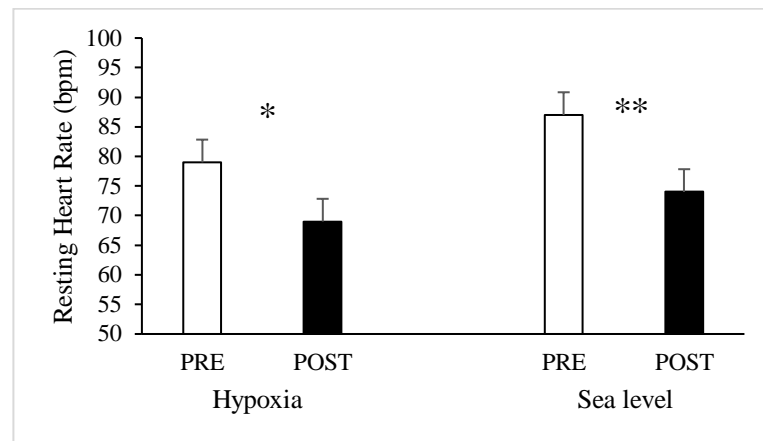


Figure 11. Mean resting heart rate of the hypoxic and sea level training groups before and after training. Note: * $p < 0,05$. ** $p < 0,01$

7.3.5 Lactate threshold(W)

Figure 7 shows the mean values obtained by both groups for the lactate threshold(W) before and after the training programme.

Repeated measures ANOVA was performed on Mean lactate threshold(W). There was a significant difference in the improvement in lactate threshold(W) between the two groups ($F(1,12) = 8,207$, $p = 0,014$, $\eta_p^2 = 0,406$) in favour of the group Sea Level. The expected main effect of lactate threshold(W) was highly significant ($F(1,12) = 33,520$, $p < 0,001$, $\eta_p^2 = 0,736$)

in favour of the moment post. No significant differences were observed in the interaction between the moment and the group ($p=0,311$).

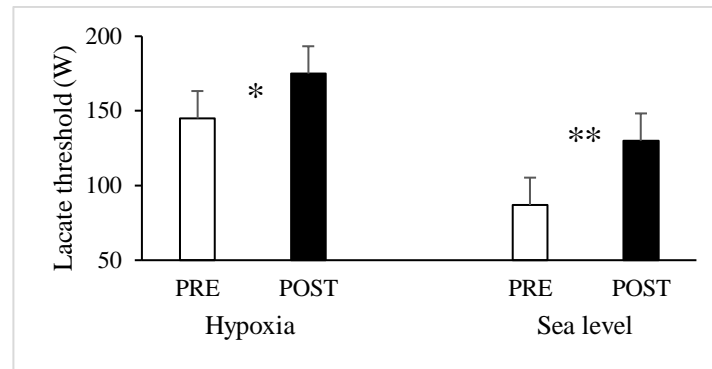


Figure 12. Mean lactate threshold(W) of the hypoxic and sea level training groups before and after training.
 Note: * $p < 0,05$. ** $p < 0,01$

7.3.6 Blood pressure

Repeated measures ANOVA were developed with mean of SBP and DBP. No statistically significant differences were observed between groups in SBP ($p=0,819$) or DBP ($p=0,516$). Statistically significant differences were observed in the effect of the moment in SBP ($F(1,12) = 10,768$, $p = 0,007$, $\eta_p^2 = 0,473$) in favour of the moment post but no differences were found in DBP ($p=0,196$). The intervention has produced the same effect in both groups, as no significant differences in the interaction between the time and the group are observed in either SBP ($p=0,524$) or DBP ($p=0,095$) (figure 8).

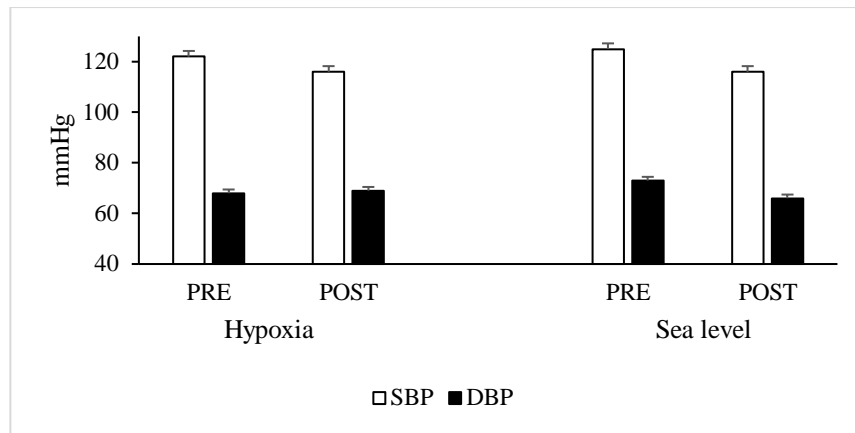


Figure 13. Mean blood pressure of the hypoxic and sea level training groups before and after training.





DISCUSSION



8 DISCUSSION

The aim of this study was to evaluate the effect of a 4 weeks training program based on HIIT under different conditions of simulated altitude on physiological variables related with strength and endurance performance. With the purpose of being able to design more efficient training programs.

The most important finding in the present study was four weeks of hypoxia training at moderate to high intensity (85-90% of maximum heart rate) in untrained subjects has been shown to produce similar increases in aerobic and anaerobic performance compared to the same sea level training program.

The time and intensity of the protocol used may not be adequate to generate the expected adaptations. In the study conducted by Meeuwsen et al. (2001) the total time of exposure to hypoxia is 20h, in this study the total time is 4h. This may mean that the total time used was not enough.

The study was started on the basis that there were no initial differences in the different variables between the two groups (hypoxia group vs. normoxia group) except for lactate threshold in (W). Significant differences were found between the two groups ($p=0.009$), in favour of the hypoxia group. The following sections will analyse all the variables discussed.

8.1 MAXIMUM OXYGEN VOLUME

In theory, by using intermittent hypoxic training, it is possible to improve aerobic capacity, which is often assessed by the $\text{VO}_{2\text{max}}$. However, intermittent hypoxic training is not yet considered an effective method of improving aerobic capacity at sea level in current research results. (Czuba et al., 2013).

In the present study the results show an increase in the pre and post effect in both groups, so we can conclude that both groups respond to the training program. But when comparing between groups we found no statistically significant differences in VO_2max . Therefore, the increase in VO_2max was not due to acute exposure to normobaric hypoxia.

Truijens et al. (2003) observed no increase in VO_2max in swimmers after an interval program of less than 60 seconds, at high intensity in intermittent hypoxia.

Very similar protocols were used to the present study, where short time exposures to hypoxia were used by high intensity training, with no significant improvement in VO_2max (Engfred et al., 1994; Geiser et al., 2001; Levine et al., 1992; Morton & Cable, 2005).

Based on our results and the results obtained by the previous authors, we conclude that the time spent on hypoxia is not enough for the improvement of VO_2max , but it would be necessary to improve several things in the protocol, indicated in improvement proposals, in order to make the study more conclusive.

8.2 MAXIMAL STRENGTH

The results obtained show that there has been no improvement in the 1RM between groups, therefore exposure to hypoxia has not been effective. But neither have improvements been obtained at the pre-post moment, so it can be concluded that the application of a HIIT program would not be the most optimal method if the objective is to increase maximum leg press. Thus, there may be a lack of transference between the 1RM test (what has been measured) and the protocol (what has been trained). The descriptive shows that there was only one trend to improve the RM in the sea level group. This, could be due to the fact that the hypoxia group started with a better physical condition, increasing the number of samples, could be confirmed.

This is consolidated, when comparing two training programs, here it was observed that the use of a HIIT program does not produce the increase of 1RM in parallel squats (Petré et al., 2018).

Astorino et al. (2012) compared between a group that performed HIIT and a control group, did not obtain benefits in the production of muscle strength.

8.3 HAEMOGLOBIN CONCENTRATION

One of the target adaptations was to increase the haemoglobin concentration with intermittent hypoxia training (Czuba et al., 2018).

There was a significant main effect of moment in favour of the moment post but only in the group Sea level is statistically significant. This may be because the initial physical state was higher in the hypoxia group. In later studies it would be necessary to adjust the groups, so that the data are more reliable. However, no differences were observed between the Sea level group and the hypoxia group, concluding that the performance of intermittent hypoxia training in the present study does not provide improvements in haemoglobin concentration.

By comparing the haemoglobin concentration between two groups of cyclists, no significant differences were found in the group that performed hypoxic interval training (Czuba et al., 2011).

Truijens et al. (2003) observed no increase in haemoglobin concentration in swimmers after an interval program of less than 60 seconds, at high intensity in intermittent hypoxia.

8.4 HEART RATE

After the intervention, no significant improvement has been observed when comparing

results between normobaric hypoxia group and Sea level group. Concluding the intervention has not caused any effect on the heart rate between groups. But on the other hand, if significant differences were observed between the pre and post moment, this indicates that the intervention has caused a decrease in heart rate in both groups.

Roels et al. (2005) observed no improvement in heart rate between the intermittent hypoxia group and the control group in cyclists after 7 weeks of training.

8.5 LACTATE THRESHOLD (W)

The most significant result has been observed in the lactate threshold (W) as well as previous variables, the intervention produced an effect in the pre and post moment, this suggests that the application of the program in both groups produces improvements in the lactate threshold (W) (Morton & Cable, 2005). Compared to previous literature, the use of HIIT is a valid protocol, to improve lactate threshold (W). But a comparison between groups shows significant differences in favour of the Sea level group and not the hypoxia group, which was expected. This may be due to a limitation, due to the starting physical condition of both groups.

8.6 BLOOD PRESSURE

The results of the present study show no significant differences between groups, meaning that no improvement in blood pressure was produced by exposure to hypoxia. Pre and post improvements in SBP were observed, but not in DBP in both groups, so the training program may improve SBP.

Astorino et al. (2012) evaluated the effects of short-term high-intensity interval training with no improvement in DBP after the intervention.

8.7 LIMITATIONS OF THE PRESENT STUDY

After the study has been performed and the results analysed, possible factors that could have limited the results of the study appear.

The sample size is one of the factors that can limit the study the most, because the number of participants is not very high, when performing statistical tests can be increased the risk of error, by not detecting a significant difference.

A second limitation the study faces is that it is not conducted by a research grade.

Another major limitation of the study may consist of the group selection test, after being randomly assigned to an experimental or control group, no group readjustment was made when an initial difference was observed. It was observed that the group randomly assigned as an experimental group had higher values in the variables analysed with respect to the control group.

Finally, two limitations during the protocol consisted in controlling the intensity of the interval and recovery. The intention was to perform the interval at 85-90% of the maximum heart rate, but not all subjects took the same time to reach this percentage, nor did they manage to maintain this percentage for the same amount of time. The recovery rate was set at 60% of the maximum heart rate, but the subjects did not recover at the same speed and consequently the next interval was conditioned. In conclusion, in a research project, establishing the intensity by means of the heart rate is not the most appropriate option.

8.8 IMPROVEMENT PROPOSAL

In order to improve future research in this area, several improvements are proposed.



The first proposal for improvement would be to adjust the groups, in order to avoid big initial differences between the two groups. A second proposal for improvement would be to adjust the intensity of the protocol using another parameter as the use of the MAS/MAP. Due to the fact that, as explained in the theoretical framework, it is the most reliable parameter to determine the intensity in a HIIT protocol.



CONCLUSION



9 CONCLUSION

- There are no effects on VO_2max after the application of intermittent hypoxia training on untrained subjects.
- There are no effects on threshold lactate after the application of intermittent hypoxia training on untrained subjects.
- There are no effects on 1RM after the application of intermittent hypoxia training on untrained subjects.
- There are no effects on heart rate after the application of intermittent hypoxia training on untrained subjects.
- There are no effects on haemoglobin concentration after the application of intermittent hypoxia training on untrained subjects.
- There are no effects on blood pressure after the application of intermittent hypoxia training on untrained subjects.
- Despite being performed at the same intensity, assuming greater effort for the hypoxia group, this is reflected in the weekly RPE.
- The present data suggest that if there is any advantage in sea level performance in using an intermittent hypoxia condition program versus the same program at sea level, it would not appear using a short time protocol as in the present study.
- Future research should subject individuals to longer periods of exposure during high-intensity training, thus likely to improve aerobic and anaerobic performance more than at sea level.





BIBLIOGRAPHY



10 BIBLIOGRAPHY

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ANNEXES



11 ANNEXES

Annex 1. Data Collection Spreadsheet

Participant code	GROUP	Age (years)	Height (cm)	WeightPre	WeightPost	1RMpre (kg)	1RMpost	Vo2 maxP	Vo2 maxPost	BMIpre	BMIpc	Fat%P	Fat%P	Muscl	Muscle	%LT(W)Pre	LT(W)Pre
HYP_01	HYP	20	180.9	68.0	68.5	129	146	35	39	20.8	20.9	21.6	22.5	37.1	36.4	125	157
HYP_02	HYP	19	184.4	87.5	82.5	230	209	45	49	25.9	24.4	24.3	23.9	38.0	38.7	160	184
HYP_03	HYP	19	183.0	69.5	71.9	193	209	52	55	21.0	21.7	10.5	12.3	43.5	43.1	165	178
HYP_04	HYP	23	175.5	74.2	73.5	243	185	47	53	24.1	23.93	16.8	16.9	42.1	41.5	183	224
HYP_05	HYP	20	160.0	61.2	62.0	115	152	35	39	23.9	23.9	28.0	27.5	33.2	33.9	105	114
HYP_07	HYP	20	162.5	58.2	59.9	170	171	36	39	21.6	23.2	21.1	25.8	36.5	35.2	115	133
HYP_08	HYP	20	190.5	85.2	82.8	170	152	38	45	23.5	22.7	25.6	21.1	36.4	37.9	165	234
NORM_01	NORM	19	175.2	63.3	65.7	162	159	48	50	20.7	21.5	11.5	14.2	42.3	41.5	65	127
NORM_02	NORM	18	173.5	65.0	65.6	97	124	34	38	21.6	21.9	15.3	16.7	40.3	39.6	115	120
NORM_03	NORM	21	168.5	60.0	61.5	123	128	31	35	21.1	21.5	27.5	29.2	33.4	32.6	30	105
NORM_04	NORM	19	175.0	86.1	85.6	129	132	23	26	28.1	28.0	43.2	43.0	27.2	28.4	91	112
NORM_05	NORM	19	181.4	75.0	74.4	193	217	48	49	22.8	22.5	12.4	14.5	43.1	42.5	145	170
NORM_06	NORM	20	179.5	99.2	93.6	145	160	28	34	30.5	28.6	33.9	31.7	32.1	33.3	110	162
NORM_07	NORM	18	159.4	53.4	54.0	118	119	35	37	21.1	21.3	25.3	23.3	32.2	33.3	53	111

Annex 2. Data Collection Spreadsheet

HaemoglobinPre	HaemoglobinPost	RestingHRpre	RestingHRpost	Resting SBPpre	Resting SBPpost	Resting DBPpre	Resting DBPpost
131	135	77	74	106	99	70	57
179	175	96	84	125	122	68	76
169	179	71	72	127	136	66	66
147	158	78	66	136	116	72	73
135	154	85	62	107	106	60	73
122	126	70	66	128	124	62	66
160	163	76	62	128	110	75	69
137	140	81	75	136	115	76	61
137	168	95	80	122	112	77	69
135	142	90	73	120	108	79	65
137	144	100	84	129	117	78	64
146	156	71	66	135	131	63	70
130	155	80	75	114	118	67	66
130	129	93	65	120	109	70	65